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THE ELENA PROJECT: PROGRESS IN THE DESIGN

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Abstract

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INTRODUCTION

The ELENA machine will be installed in the AD hall at CERN. It will sit geometrically inside the AD ring, at the place currently used by the kicker generators (See Fig.1).

Two extraction lines are planned, one to eject particles towards the existing experiments (ASACUSA, ALPHA, ATRAP, ACE and AEGIS) and on the other hand towards possible future experiments. It is planned at this stage to accommodate at least one new experiment exploiting ELENA beams. The creation of this new experimental area, which currently is occupied by the AD workshop, is directly linked to the proposed construction of an extension of the AD hall, otherwise the kicker generators will use this space.

An 800 mm thick concrete shielding around the new machine and the new experimental areas is sufficient to ensure radiation levels in case of total beam loss of below 3 μSv/h at any point in the hall and below 0.5 μSv/h on the planned visitor platform.

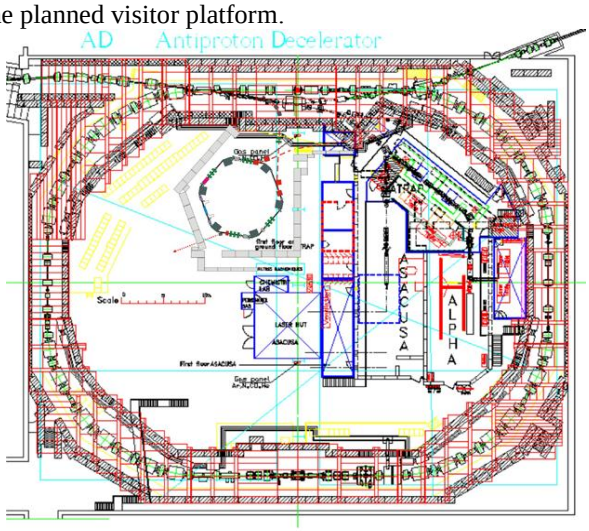

Figure 1: ELENA and AD layout

ELENA INJECTION

Before extraction from AD the beam is cooled at 100 MeV/c and bunched. Typical AD beam has a non-gaussian transverse distribution with a compact core and extended tails. The acceptances of AD transfer line are 15 π·mm·mrad and beam losses might occur during transfer to ELENA. Adjustment of the electron cooling by making a small misalignment between the electron and antiproton beams is foreseen. This modifies the beam profiles to be Gaussian-like, with 95% of beam having emittances less than 10 π·mm·mrad. The appropriate studies in AD have been performed and confirmed this possibility.

The existing AD extraction line will be modified, some elements will be removed to save space inside the AD ring area and to install two bending magnets of 41° each and one quadrupole in between. After crossing the AD ring shielding the line is equipped with additional quadrupoles, instrumentation and vacuum equipment.

THE ELENA CYCLE

Right after injection into ELENA at 100 MeV/c the beam is decelerated to 35 MeV/c where electron cooling is applied in order to eliminate deceleration losses caused by beam blow up [1] [2]. Cooling is applied a second time after deceleration to an extraction momentum of 13.7 MeV/c in order to achieve required values for beam emittances and momentum spread (See Fig.2).

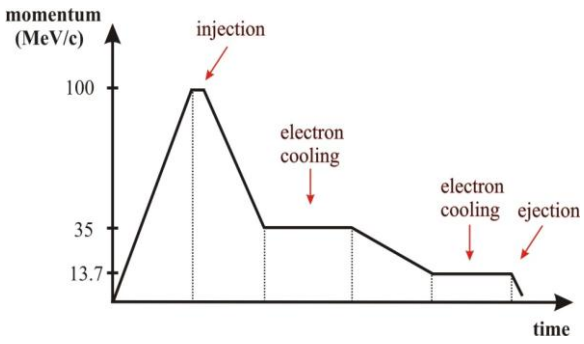

Figure 2: ELENA cycle

The extraction momentum of 13.7 MeV/c is defined by vacuum requirements, quality of the ultra-low energy electron beam and for bunched beams also by intensity limitations due to space charge induced tune shift and due to Intra Beam Scattering (IBS).

After cooling, bunching and RF gymnastics, one to four 1.3 m long bunches will be extracted to the experiments.

Table 1: ELENA machine and beam parameters

Momentum range, MeV/c	100 – 13.7
Energy range, MeV	5.3 – 0.1
Circumference, m	30.4
Intensity of injected beam	$3 \cdot 10^7$
Total intensity of ejected beam	$1.8 \cdot 10^7$
Number of extracted bunches	1 to 4
Emittances (h/v),π·mm·mrad,[95%]	4/4
Δp/p after cooling, [95%]	$2 \cdot 10^{-4}$
Bunch length at 100 keV, m /ns	1.3 / 300
Required (dynamic) vacuum, Torr	$3 \cdot 10^{-12}$
Machine tunes h/v	2.3/1.3

RING LATTICE, MACHINE PARAMETERS AND ISSUES

ELENA optics choices are strongly dictated by various constraints [3]. The ring should fit the limited space available in AD hall and allow for ELENA construction and commissioning without major disturbance to the AD physics program. The ring has to be configured for one injection and two ejection lines. A long straight section must be foreseen for the electron cooler with appropriate beta function and dispersion values.

A circumference of 1/6 of the AD ring was chosen to provide enough space for equipment. Hexagonal ring layout was found much more suitable than rectangular for beam injection and two extractions within the designated AD Experimental Area. Three quadrupole families are used to control tunes (Qh=2.3, Qv=1.3) and to some extent beta function values in the electron cooler. The edge angle at the entrance and exit of each bending magnet has been varied and finally chosen equal to 18°. The lattice functions are shown in Fig. 3.

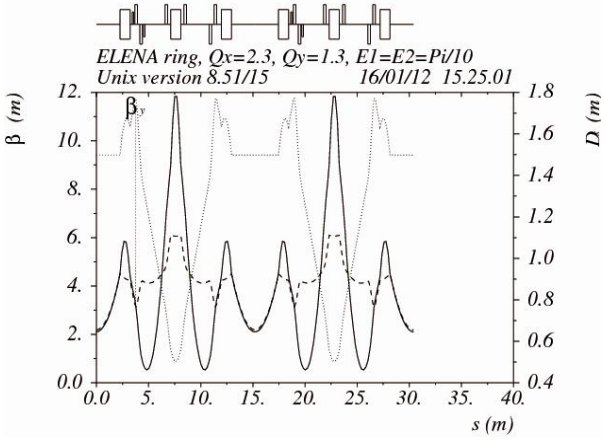

Figure 3: ELENA ring lattice functions

Choice of extracted beam parameters is mainly limited by transverse space charge. Maximum bunch length accepted by the experiments is 1.3m. Beam size is critical and emittances must be controlled at the end of the cooling process. Main parameters are given in Table 1.

First investigations on IBS indicate very fast mainly longitudinal blow-up of the cooled beam at 100 keV. More detailed studies are carried out at present to better estimate and optimize beam parameters at 100 keV including blow-up during the last deceleration and the impact on required machine acceptances.

First studies of residual gas effects showed that with a pressure of $3 \cdot 10^{-12}$ Torr many antiprotons do not interact at all during a typical 100 keV plateau with a rest gas molecule. Thus, both beam losses due to large angle scattering and blow-up due to small angle scattering are dominated by single scattering events. Both loss rates and blow-up (neglecting particles undergoing large angle scattering) are significant, but not yet a serious limitation.

Beam coupling impedances and beam stability and, if required, cures against instabilities like a transverse damper, will be studied.

VACUUM

Beam physics considerations call for an average pressure of around $3 \cdot 10^{-12}$ Torr and a gas composition mainly given by hydrogen and low-Z gas species, meaning extreme high-vacuum regime (XHV).

All vacuum chambers are made of austenitic stainless steel with low permeability, e.g. 316LN. Vacuum firing all materials in-house is considered. Massive NEG-coating is applied everywhere possible, in order to reduce the gas load and obtain a distributed pumping profile for getterable gases. Additional pumping is installed on each dipole magnet and on each straight section, by using integrated NEG and ion-pump combinations. Additional pumping is foreseen on the injection and on the two extraction elements and on the electron-cooler, possibly using NEG-strips on the latter as done on the AD machine, but the details of this have not been defined yet. The vacuum system is designed for a 300 C bakeout and NEG-coating activation and all-metal gate valves and ConFlat-type joints are envisaged everywhere. Similar solutions are implemented for the experimental beam lines: a low net outgassing rate is particularly important in the area near the ELENA ring, as backstreaming of gas species from the experimental beamlines to the ring should be minimized, given the average pressure requirements.

ELECTRON COOLING

The cooler will be based on the device that was built for the S-LSR ring [4] in Japan and will incorporate adiabatic expansion to reduce the electron beam temperature as well as electrostatic bending plates for efficient collection of the electron beam. Work is on-going to optimize the gun design and cooling simulations using Betacool [5] will help to fine-tune the final parameters of the cooler. Main parameters of the cooler are specified in Table 2.

Table 2: Electron Cooling Parameters

Momentum	**35 MeV/c**	**13.7 MeV/c**
β	0.037	0.015
E beam energy	355 eV	55 eV
E current	10 mA	1 mA
E beam density	2.8×10^{12} m^{-3}	7.2×10^{11} m^{-3}
Expansion factor	10	
Cathode radius	7.9 mm	
E beam radius	25 mm	

BEAM INSTRUMENTATION

To measure the closed orbit during the deceleration cycle 10 electrostatic beam position monitors will be installed inside the ring quadrupoles and compensation solenoids. Their expected resolution is 0.1 mm with an accuracy of 0.3 to 0.5 mm. A prototype should be ready in 2013 and the manufacturing of the units will follow a year later. The tune measurement system based on the BBQ systems used on other rings [6] will use one pick-up to provide the tune evolution throughout the cycle.

As in the AD, it is planned to use a high sensitivity longitudinal Schottky pick-up to measure the beam intensity. Nevertheless, investigations are being made to check the feasibility of using a superconducting DCCT to make this low intensity measurement.

Scrapers will be used to destructively measure the transverse profile (and hence emittance) of the circulating beam. Ionisation profile monitors could also be used but they have the detrimental effect of inducing a strong transverse kick on the beam and the gas injection system required to increase the ionisation rate will cause a large bump in pressure around a significant proportion of the circumference.

EJECTION FROM ELENA

At 100 keV, a single fast electrostatic separator can be used to extract all bunches at once with subsequent switching into the different transfer lines. Since recuperation of existing equipment is more expensive than building a more flexible new hardware, the obvious choice is to proceed with the design of an electrostatic extraction system.

The transfer lines transport beams with a 95% emittance of 4 π·mm·mrad in both planes to the experiments. One extraction will serve the four existing experimental lines while the other can serve two new experiments. In case of extraction of several bunches at once a fast deflector as used for extraction is required to distribute single bunches into the different experimental beam lines. A preliminary geometric design of the beam lines aims at maximising the distance from superconducting magnets of the experiments which can disturb the beam trajectory in the transfer lines during the field ramp.

The steering and focussing elements in the lines are considered to be electrostatic. Preliminary optics studies suggest a maximum operation voltage for quadrupoles of 5 kV considering a full aperture of 60 mm. The vacuum chamber will be equipped with up to three shielding layers to avoid influence from magnetic stray fields. Low-energy beam profile monitors [7] are foreseen to measure beam position and profile. Cherenkov counters for the timing profile and aluminium activation foils for absolute intensity measurement are envisaged [7].

PLANNING

For ELENA design, construction, installation and commissioning the main milestones and planned activities are:

- 12/2012: Publish Technical Design Report.
- 01/2013 – 02/2014: AD Hall modifications.
- 10/2013: AD Hall extension (new building) completed.
- 11/2013 – 03/2014: Move kicker generators to new location.
- 01/2014 – 03/2015: ELENA installation.
- From 04/2015: ELENA ring commissioning in parallel with the physics program.
- 12/2015 – 04/2016: Installation of new electrostatic beamlines to the experiments.
- 04/2016 – 06/2016: Commissioning of the new beamlines.
- 07/2016: Start of physics with 100 keV Pbars.

CONCLUSION

The ELENA project is started and the Technical Design Report is underway. A low beam extraction energy of 100 keV will increase the number of trapped antiprotons at the experiments by one to two orders of magnitude compared to now. Efficient beam deceleration and adequate beam parameters for extraction are provided by electron cooling. Special care is paid to beam extraction due to severe limitations in bunch intensity, length and emittances caused by space charge effects and IBS.

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